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HIGH-SPEED OSCILLATING TESTS OF LUBRICATING COMPOSITES

Peter Martin, Jr., et al

Army Weapons Command
Rock Island, Illinois

November 1972

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U.S. ARMY WEAPONS COMMAND

TECHNICAL REPORT

Peter Martin Jr.

and

George P. Murphy

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RESEARCH DIRECTORATE

WEAPONS LABORATORY, WECOM

RESEARCH, DEVELOPMENT AND ENGINEERING DIRECTORATE

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13. ABSTRACT

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Twenty-five self-lubricating composites, both plastic and metal-based, were compared by personnel of the Research Directorate, Weapons Laboratory, WECOM, on the LFW-1 tester in the oscillatory mode of a 75-degree arc and 200 cycles per minute by use of test loads of 30, 60, and 120 pounds. A metal-based composite composed of molybdenum, molybdenum disulphide, niobium, and copper gave the best friction and wear results of any of the composites tested against either steel or hard-anodized aluminum. For the plastic-based composites, epoxy resin plus graphite fibers or polyamide resin plus graphite gave the best results when tested against steel, whereas polyimide resin plus graphite and PTFE or polyamide resin plus PTFE gave the best results when tested against hard-anodized aluminum.

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INTRODUCTION

Considerable work has been done in recent years to develop lubricating composites for use in bearings and gears that make operation possible without conventional lubricants such as oils and greases. Dry film lubricants have also been replaced by lubricating composites since these films have a finite wear-life and must be replaced or repaired. Lubricating composites offer the most promise of current solid-lubricant technology since many more applications are possible. For example, composites can be machined or formed into various configurations and provide dry, dust-free lubrication.

Currently, two main types of lubricating composites have been developed. These composites are metallic and plastic-based types fortified with solid lubricants, fillers, and reinforcement materials. They are formed by vacuum impregnation, sintering, compaction, and injection molding. Discussions on these composites are given by Campbell[1,2] along with information on mechanical properties and comparative performance data.

Since the greatest attribute of lubricating composites is the concept of permanent lubrication for the life of the system, the Army is investigating its potential application. Small arm weapons would be a logical application since these weapons require periodic maintenance consisting of relubrication, corrosion protection, and cleaning. Therefore, to make use of the current technology, a program was initiated to study the feasibility of utilizing solid lubricating composites for specific small arms weapons components.

Some evaluation work[3,4] on various lubricating composites has been accomplished under conditions of oscillating motion, light loads, and low speeds. However, in small arms, the components are subject to oscillating or reciprocating motion, instantaneous high loads and high speeds.

APPROACH

In this report, a study is described that was designed to examine the friction and wear properties of lubricating composites under oscillating motion at high loads and high speeds within the limits of commercially available apparatus. This study could lead to a group of recommended lubricating composites and possible application of them to areas of small arms weapons.

EQUIPMENT AND MATERIALS

Friction and wear measurements were determined by use of the high-speed model LFW-1 friction and wear testing machine equipped with an oscillating drive In this machine, a stationary block is loaded against a ring, as shown in Figure 1 With an oscillating drive, the variable high-speed model of the machine is capable of oscillating the ring through a fixed arc, which may range from 0 to 90 degrees, at frequencies ranging from 0 to 600 cycles per minute

Other equipment used included a balance to measure the weight change of the materials tested to the nearest 0 1 mg Also, a single-channel recorder for the continuous recording of frictional force

Composite materials received were machined according to dimensions of the standard blocks The compositions of the commercial lubricating composites used in this study are given in Table I The composites are arranged into groups of polyimides, polyamides, polyesters, epoxys, polytetrafluoroethylene (PTFE), and metal base

The steel rings were made of 4620 steel having a hardness R_C 60 and 20-30 rms finish These rings were scrubbed with hot petrolene and were then air-dried

The aluminum rings were made of 7075-T6 aluminum The rings were hard-anodized according to MIL-A-8625C, Type III, Class 3, and were used without further treatment.

PROCEDURE

The test procedure consisted of the initial weighing of the specimen block and ring to the nearest 0 1 mg The test conditions chosen were a 75-degree angle of oscillation or length of travel and a frequency or speed to 200 cycles per minute These conditions represent the maximum attainable linear velocity for the high-speed model LFW-1

Tests were conducted at 30-, 60-, and 120-pound loads These loads were applied under dynamic conditions from zero to total test load to avoid abrupt load application The load was increased in 10-pound increments at one-minute intervals for the 30- and 60-pound test loads. For the 120-pound test load, increases were made in 30-pound increments at one-minute intervals Each test was conducted for a one-hour period. The frictional behavior of the

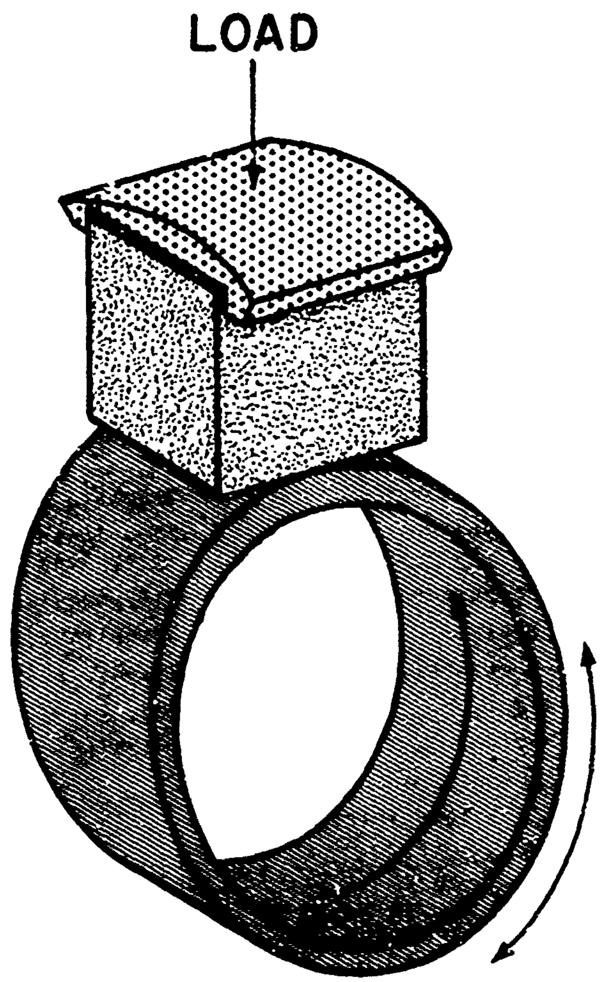

FIGURE 1 Test Configuration for LFW-1 Friction and Wear Tester

TABLE I

COMPOSITION OF LUBRICATING COMPOSITES

Lubricating Composite	Base Material	Solid Lubricant	Fillers
1	Polyimide	---	---
2	Polyimide	Graphite	---
3	Polyimide	MoS_2	---
4	Polyimide	Graphite, PTFE	---
5	Polyimide	Graphite	---
6	Polyimide	Graphite, PTFE	---
7	Polyimide	PTFE	bronze
8	Polyimide	WS_2	Ag
9	Polyamide	---	---
10	Polyamide	Graphite	---
11	Polyamide	PTFE	---
12	Polyester	---	---
13	Polyester	Graphite	---
14	Polyester	Fluorinated ethylene propylene	---
15	Polyester	Polyphenylsulfide	---
16	Epoxy	Graphite fiber	---
17	Epoxy (high temp)	Graphite fiber	---
18	Epoxy	MoS_2	---
19	Nylon	Graphite	---
20	Nylon	---	glass
21	Cellulose phenolic	---	---
22	Bronze	MoS_2	---
23	Silver	PTFE, MoS_2	---
24	Gallium-Indium	WSe_2	---
25	Molybdenum	MoS_2	Nb, Cu

specimens was periodically monitored. Initial coefficients of friction were determined immediately after the test load was reached. Final coefficients of friction were determined at the end of 60 minutes.

After completion of the test, both the specimen block and the ring were weighed and the weight loss or gain determined.

The wear rates were calculated from the composite weight loss by use of the equation

$$\text{Wear rate} = \frac{\frac{W}{d}}{LD}$$

In this equation, W = weight loss of composite (gms),

d = density $\left(\frac{gms}{cc^3}\right)$, L = load (Kgs), and D = distance

traveled (cm). In addition, the width of the wear scar on the block was measured. The final loads (psi) were determined by division of the test load by the area of the wear scar (sq. in.).

RESULTS AND DISCUSSION

Screening tests were conducted in this study for selection of composite materials for possible application in small arms weapons. The data presented are those for the average results of at least duplicate tests for each condition. These data are shown in Tables II, III, and IV with the steel as the mating surfaces, and in Table V with aluminum rings as the mating surfaces.

The wear rate of the polyimide base resin (No. 1) is reduced by addition of solid lubricants with the exception of composite No. 7. Apparently the bronze filler increased the wear rate.

However, with an increase of the test load to 60 pounds, the wear rate of polyimide base resin increased significantly. While the polyimide composites containing solid lubricants had wear rates less than the base resin.

TABLE II

FRICTION AND WEAR TESTS OF LUBRICATING COMPOSITES AGAINST STEEL AT 30-POUND TEST LOAD

Composite	Initial Coefficient of Friction	Final Coefficient of Friction	Weight Loss (mg)	Wear Scar (mm)	Load at End of Test (psi)	Wear Rate $(cm^3/cmkg) \times 10^{-10}$
1	0.36	0.37	1.6	3.61	855	14.8
2	0.37	0.42	0.8	2.55	1200	6.82
3	0.34	0.44	0.6	2.13	1470	5.54
4	0.24	0.29	0.8	2.90	1060	6.93
5	0.34	0.35	0.4	2.00	1575	3.52
6	0.25	0.29	0.3	2.02	1520	2.60
7	0.20	0.20	5.0	3.78	750	21.0
8	0.42	0.50	0.5	2.66	1150	3.74
9	0.34	0.44	1.6	3.81	800	16.8
10	0.26	0.28	0.2	1.76	1750	2.50
11	0.22	0.16	0.8	2.55	1200	7.75
12	0.38	0.24	8.2	6.04	500	77.8
13	0.26	0.42	5.7	5.16	600	53.2
14	0.19	0.15	19.4	7.97	380	182.0
15	0.35	0.33	5.4	5.62	550	52.3
16	0.20	0.22	0.4	1.90	1575	2.84
17	0.20	0.24	0.3	2.07	1515	2.45
18	0.20	0.32	7.1	3.62	850	35.0
19	0.22	0.30	12.4	6.44	480	287.0
20	0.22	0.20	12.7	7.62	400	154.0
21	0.24	0.34	0.8	2.42	1260	7.45
22[(a)]	0.54	0.71	2.8	2.79	370	44.1
25	0.15	0.05	0.1	1.37	2300	0.224

(a) Results given are for 30 minutes at 10-pound test load. Wear on test ring.

TABLE III

FRICTION AND WEAR TESTS
OF LUBRICATING COMPOSITES AGAINST STEEL AT 60-POUND TEST LOAD

Composite	Initial Coefficient of Friction	Final Coefficient of Friction	Weight Loss (mg)	Wear Scar (mm)	Load at End of Test (psi)	Wear Rate $(cm^3/cmkg)x10^{-10}$
1	0.33	0.26	15.7	7.50	825	73.5
2	0.34	0.34	3.5	4.37	1405	14.9
3	0.32	0.32	1.4	3.52	1760	6.18
4	0.26	0.26	1.8	3.46	1780	7.78
5	0.36	0.36	2.0	4.13	1515	9.17
6	0.22	0.27	2.4	3.62	1700	10.6
7	0.19	0.19	8.6	4.96	1150	18.3
8	0.37	0.40	1.4	3.53	1730	5.06
9	0.34	0.49	4.0	4.95	1240	21.0
10	0.29	0.27	0.8	2.18	2880	3.99
11	0.21	0.14	1.4	4.02	520	6.85
12[(b)]	0.26	0.19	24.1	8.60	715	350.0
14[(b)]	0.18	0.16	25.6	8.44	740	359.0
15[(a)]	0.30	0.24	19.4	7.74	790	125.0
16	0.22	0.23	1.1	2.60	2360	4.67
17	0.23	0.24	0.8	2.51	2500	3.26
18	0.22	0.16	8.6	4.53	1370	21.0
19[(a)]	0.25	0.35	9.7	6.75	900	112.0
20[(a)]	0.28	0.23	15.6	8.07	770	166.0
21	0.23	0.28	2.0	3.47	1760	9.31
23	0.13	0.13	114.4	8.10	762	92.5
24	0.06	0.05	7.4	2.67	2300	6.60
25	0.05	0.02	0.3	1.59	3960	0.336

(a) Test terminated after 30 minutes, excessive wear.
(b) Test terminated after 20 minutes, excessive wear.

TABLE IV

FRICTION AND WEAR TESTS OF LUBRICATING COMPOSITES AGAINST STEEL AT 120-POUND TEST LOAD

Composite	Initial Coefficient of Friction	Final Coefficient of Friction	Weight Loss (mg)	Wear Scar (mm)	Load at End of Test (psi)	Wear Rate $(cm^3/cmkg) \times 10^{-10}$
8[a]	0.32	0.29	24.6	8.40	1450	92.4
10	0.20	0.26	1.7	2.82	4360	4.25
11	0.15	0.11	3.2	4.23	2900	8.40
16	0.20	0.18	1.6	3.81	3225	3.76
17	0.20	0.17	1.7	4.02	3125	4.18
25	0.03	0.02	0.5	1.67	7550	0.308

(a) Test terminated after 30 minutes, excessive wear.

TABLE V

FRICTION AND WEAR TESTS
OF LUBRICATING COMPOSITES AGAINST ANODIZED 7075-T6 ALUMINUM
(TEST LOAD, 60 POUNDS)

Composite	Initial Coefficient of Friction	Final Coefficient of Friction	Weight Loss (mg)	Wear Scar (mm)	Load at End of Test (psi)	Wear Rate $(cm^3/cmkg) \times 10^{-10}$
1	0.17	0.24	15.8	7.43	830	74.0
2	0.20	0.26	4.1	4.62	1325	17.4
3	0.32	0.30	3.2	4.51	1360	13.6
4	0.11	0.21	0.6	2.12	2910	2.38
5	0.22	0.35	2.6	4.35	1440	11.8
6	0.14	0.26	0.5	2.10	2970	1.96
7	0.14	0.15	2.6	3.86	1480	5.61
8	0.34	0.38	0.3	3.16	1940	2.25
9	0.20	0.22	9.6	6.32	970	50.5
10	0.20	0.29	10.2	4.93	1250	25.2
11	0.08	0.08	1.0	3.36	1850	6.71
14	0.14	0.14	22.0	8.37	750	412.0
15	0.21	0.19	26.0	8.81	700	538.0
16	0.21	0.23	1.6	3.39	1810	6.7
17	0.23	0.23	1.7	3.86	1630	7.14
18	0.15	0.20	13.2	5.40	1150	32.4
19	0.11	0.34	1.3	4.28	1790	7.54
23	0.12	0.12	116.7	8.23	770	378.0
24	0.04	0.03	18.8	4.43	1400	16.1
25	0.07	0.05	0.2	1.16	5680	0.224

The wear rate and the coefficient of friction of the polyamide base resin (No. 9) were reduced by addition of graphite and PTFE.

The addition of various solid lubricants to the polyester base resin (No. 12) has no beneficial effect as related to the wear rate at both 30- and 60-pound test loads. At 60 pounds, the test was terminated after 20 and 30 minutes since the wear rate of the polyester composite became excessive. Also composite No. 13 was not tested because of specimen breakage in the holder.

The epoxy composites (Nos. 16 and 17) with graphite fibers had the same wear rates at 30 pounds and did not change significantly at 60 pounds. However, the epoxy composite (No. 18) with MoS_2 had a higher wear rate at 30 and 60 pounds as compared to the graphite epoxies.

The nylon composites (Nos. 19 and 20) had wear rates higher than most of the composites at 30-pound test load. At 60-pound test load, the test on the nylons had to be terminated after 30 minutes because of excessive wear.

The test with metal composite (No. 22) was tested at 10 pounds and was terminated after 30 minutes since severe galling and seizing occurred. No further tests were made on this composite.

A composite (No. 25) made of MoS_2, Mo, Nb, and Cu had the lowest wear rate and coefficient of friction of the metal-based composites. This composite had a wear rate 10 times lower than that of the best plastic composite and a coefficient of friction of 0.02 as compared to 0.14 for the plastic composite.

On the basis of performance at the 30- and 60-pound loads, four plastic composites (Nos. 8, 10, 11, 16, and 17) and one metal composite (No. 25) were evaluated at 120-pound test load. The data in Table IV indicate no significant change in the wear rates of the composites, with the exception of composite No. 8. The test on composite No. 8 had to be terminated after 30 minutes because of excessive wear.

The following composites were not tested against aluminum: composite No. 13, because of specimen breakage in holder; composite No. 22, because of severe galling and seizing at initial loading with steel. Composites Nos. 12, 20, and 21 were not tested because of insufficient material.

The polyimides, polyamides, and polyesters show the same trend with regard to the effect of solid lubricant additives on wear rates as those run against steel at 30- and 60-pound test loads (Table V).

However, of the plastic materials, composites Nos. 4, 6, and 8, which are all polyimides, demonstrated the lowest wear rates against aluminum.

As in the results against steel, the metal composite (No. 25) had the lowest wear rate and coefficient of friction of the metal-based composites. In addition, its wear rate was 10 times lower than that of the best plastic composite.

From the friction and wear rate data given in Tables II, III, IV, and V, no correlation apparently exists between friction and wear rate.

No correlation existed between the wear rate and the substrate used since the wear rate either increased or decreased dependent upon the nature of the individual composite.

The relationship between test load and wear rate for the best composites run against the steel ring is shown in Figure 2. These curves show that, with the exception of composite No. 8, the wear rate remained almost constant over the test load range of 30 to 120 pounds. The wear rate of composite No 8 increased sharply for test loads greater than 60 pounds which indicates that, for the constant speed, the limiting PV value (pressure times surface speed) of the material was exceeded at loads above 60 pounds.

The curves in Figure 3 show that, for the composites run against steel the friction decreased with increasing load particularly for loads above 60 pounds

CONCLUSIONS

The following conclusions are made with respect to frictional behavior and wear of lubricating composites tested in the oscillating mode at high speed, high loads in air.

1. For steel substrates, the best resin based composites were epoxy resin plus graphite fibers or aromatic polyamide plus graphite or PTFE. The best metal-based composite was molybdenum metal plus MoS_2, Nb, and Cu.

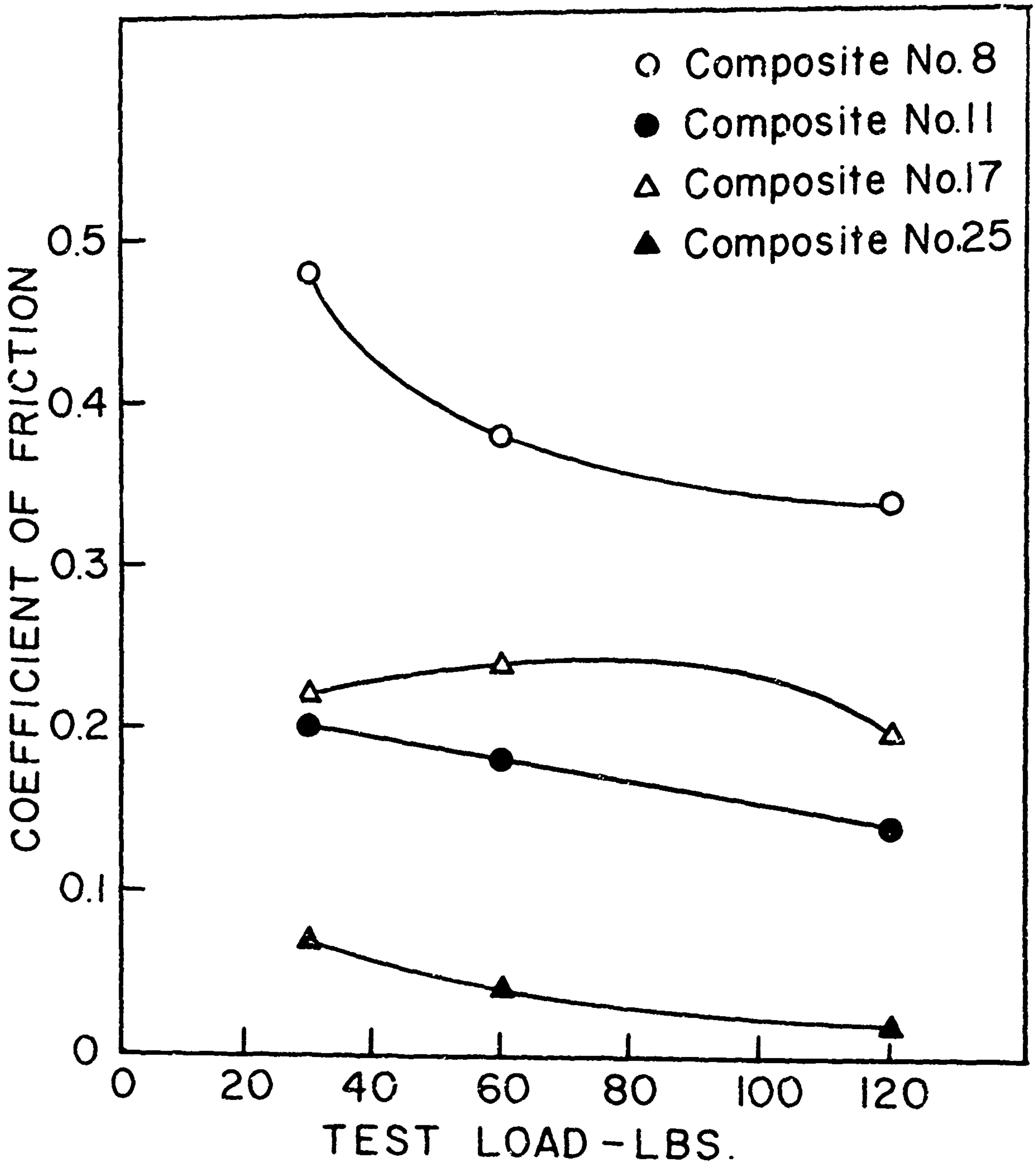

FIGURE 2 Effect of Load on Wear Rate for Various Composites (against steel)

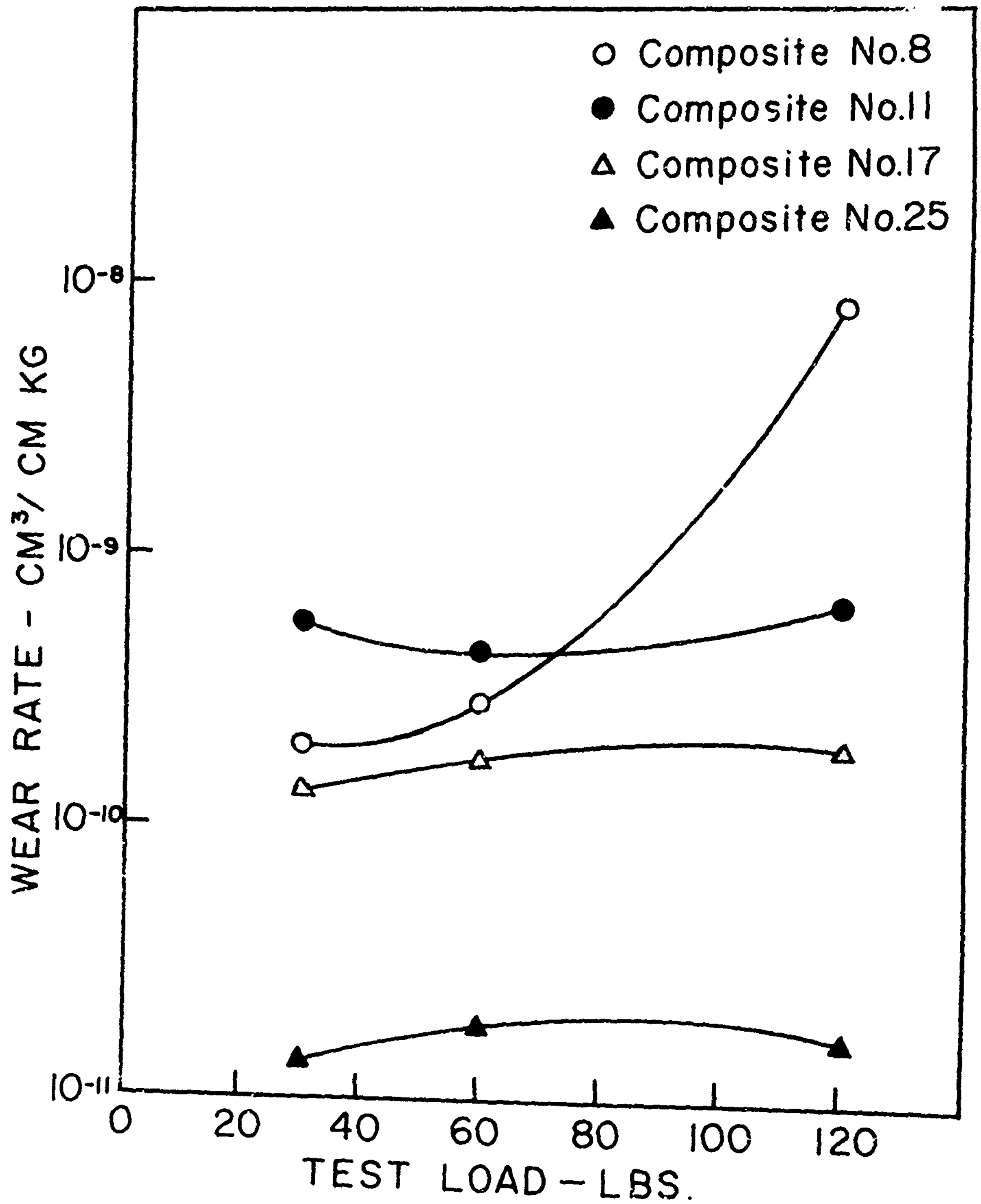

FIGURE 3 Effect of Load on Coefficient of Friction of Various Composites (against steel)

2. For hard anodized aluminum substrates the two best resin based composites were polyimide plus graphite and PTFE and polyimide plus WS_2 and Ag. The best metal based composite was molybdenum metal plus MoS_2, Nb and Cu.

3. No correlation exists between friction and wear rate of lubricating composites.

4. For those composites tested against steel, the wear rate remains essentially constant over the test load range of 30 to 120 pounds if the limiting PV value is not exceeded.

5. The coefficient of friction of the composites decreases with increased load against steel.

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